Model 2	Layered mafic-ultramafic intrusive stratabound PGE-Ni-Cu, PGE-Cr
Alternative Model Name	
Description	Bushveld-type: (1) Merensky Reef - stratabound PGE-sulphide association (2B) (2) PGE-Cr - stratabound PGE-chromite association (2A) (3) Fe-Ti-V - stratabound titaniferous magnetite/ilmenite (3)
Commodities	(1) Pt-Pd-Rh (major), Ir-Os-Ru-Au-Cu-Ni-Cr (minor) (2) PGE-Cr (major), Cu-Ni-Au (minor) (3) Fe, Ti, V
% Global Production	(1 & 2) 88% PGE (1998) (2) ~40% Cr (95% of worlds reserves) (3) >?90% V (1998), minor TiO_2
% Australian Production	(1) Nil (major prospects: Munni Munni-Pilbara, Weld Range-Yilgarn) (2) Nil (major prospects: Panton & Eastmans Bore-Kimberleys, Windimurra-Yilgarn) (3) Nil. Production will commence late 1999 at Windimurra-Yilgarn (reserve of 66 Mt @ 0.47% V_2O_5); other major prospects-Barrambie, Coates, Medcalf (all Yilgarn) and Balla Balla (Pilbara) have resources of ~15-30 Mt @ 0.4-0.8% V_2O_5, 5-15% TiO_2
World Class Deposit Size	(1) >~200 Mt @ 5g/t PGE (>1000 tonnes of metal) (Australian deposits typically 0.5-30 Mt @1-3 g/t PGE, 0.5% Cu, 0.3% Ni) (2) UG-2 has a total resource of ~32 000 tonnes contained PGE (Australian deposits typically 0.5-2 Mt @1-6 g/t PGE, 0.3% Ni) (3) ??>60 Mt @ 0.8% V_2O_5
World Class Deposit Examples	(1 & 2) Merensky Reef-Bushveld (RSA), J-M Reef-Stillwater (USA) Great Dyke (Zimbabwe) (3) Major: Bushveld (RSA), Kachkanar (Russia), Panzhihua (China) Minor: Finland, Chile, India
Geological Setting	Tholeiitic layered mafic-ultramafic intrusions in stable Precambrian cratons and more rarely in Palaeoproterozoic mobile zones
Age	Palaeoproterozoic to Archaean: generally 1.8-2.7 Ga: Bushveld (2.05 Ga), Great Dyke (2.6 Ga), Stillwater (2.7 Ga)
Components:	
Source	
Transport/Pathway	
Trap	
Critical Elements	For deposit types (1) and (2) • Differentiated mafic–ultramafic intrusions in stable Precambrian cratons and Palaeoproterozoic mobile zones (1) • Generally large (>5 km-thick) differentiated tholeiitic layered mafic-ultramafic intrusions (2) • Late S saturation (in chamber or high in conduit) of tholeiitic/SHMB magma(s) (1) • PGE-Cr deposits associated with olivine and/or orthopyroxene (not clinopyroxene) cumulates (2) • Need mineralising mechanism: turbulent mixing of compositionally distinct magmas resulting in high R factor, crustal contamination, crystal fractionation, ‘hydrothermal’ fluids (1) For deposit type (3) as well as (1) and (2) as indicated • Intrusions in stable Precambrian cratons and Palaeoproterozoic mobile

	zones (1) • Large tholeiitic mafic intrusions (2) • Differentiated sequence with favourable oxidation (fO_2) conditions during crystal fractionation (2) • Precipitation of titaniferous magnetite and ilmenite induced by closed-system fractionation processes, or by new magma pulses having different oxidation (fO_2) characteristics to resident magma (3)
Other Comments	Laterally extensive stratabound mineralised layers are generally considered magmatic in origin, but late-magmatic and hydrothermal processes have played a role in some PGE deposits; UG-2 dominates world's Cr & Pt; Windimurra is regarded as one of the largest undeveloped V deposits in the world; current renewed exploration interest of PGEs in Australia (see 10 p article in Paydirt-July 1999); Munni Munni (2.9 Ga) is one of the oldest mineralised layered intrusions in the world
Key References	Naldrett, A.J., 1989. Magmatic Sulfide Deposits. Clarendon Press; Oxford University Press, New York, 177 pp. Naldrett, A.J., 1997. Key factors in the genesis of Noril'sk, Sudbury, Jinchuan, Voisey's Bay and other world-class Ni-Cu-PGE deposits: implications for exploration. Australian Journal of Earth Sciences, 44, 283–315. Stowe, 1987. Evolution of Chromium Ore Fields, Van Nostrand Reinhold, 340 pp. Cawthorn, R.G., 1996. Layered intrusions. Developments in Petrology 15. Elsevier, Amsterdam. 531 pp. Hoatson, D.M., 1998. Platinum-group element mineralisation in Australian Precambrian layered mafic-ultramafic intrusions. Special Issue of AGSO Journal of Australian Geology & Geophysics, 17/4, 139–151. Economic Geology (vols 71/7-1976, 77/6-1982, 80/4-1985, 81/5-1986).

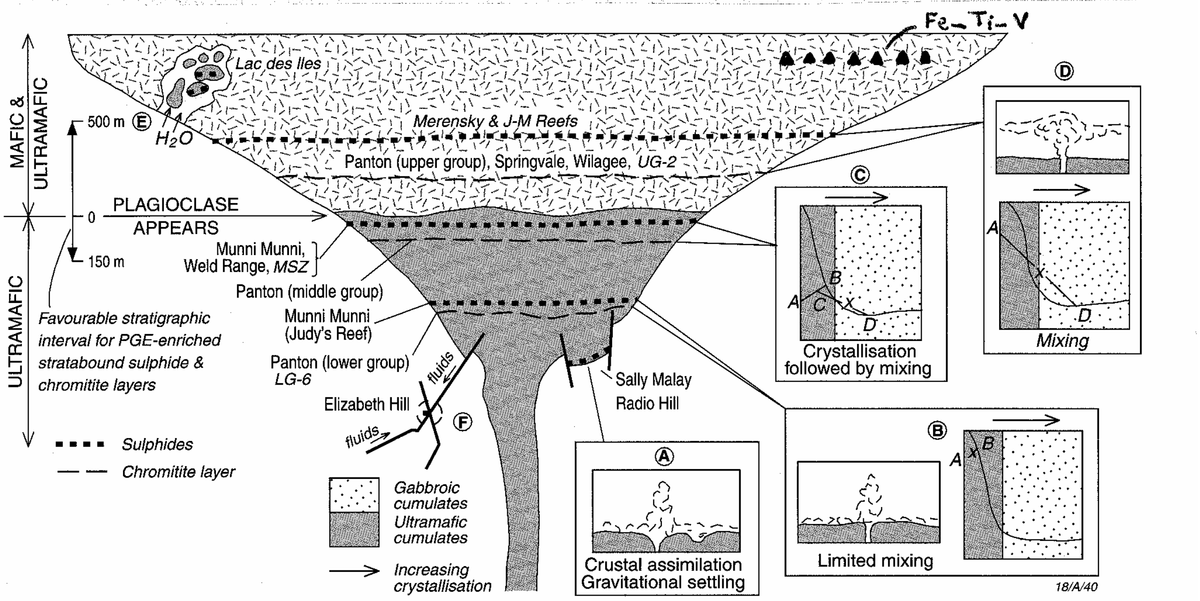

Figure 6. Summary of the different types of PGE deposit related to crustal assimilation, crystal fractionation, magma mixing, constitutional zone refining, and hydrothermal fluid mineralising processes in an idealised layered mafic-ultramafic intrusion (modified after Naldrett 1993). Early S saturation of the primitive magma by crustal assimilation, and gravitational settling of the sulphides may form PGE-poor massive sulphide deposits in embayments along the basal contact or in the feeder conduit (example A); localised fountain-type mixing (i.e. low R factor) of resident magma with primitive magma before plagioclase has appeared on the liquidus may give rise to a PGE-poor sulphide layer or chromitite (example B); crystal fractionation of a S-undersaturated PGE-bearing primitive resident magma and extensive magma mixing (i.e. high R factor) with a S-saturated gabbroic magma may give rise to a PGE-rich layer not associated with the base of a cyclic unit (example C); turbulent plume-type mixing of resident magma with a more primitive magma after the crystallisation of plagioclase may give rise to a PGE-enriched sulphide layer or chromitite layer (example D); volatile-induced partial melting of cumulates (constitutional zone refining) caused by the introduction of water into the hot cumulus pile can concentrate PGE when the partial melt becomes S saturated (example E); and structurally controlled hydrothermal PGE–base-metal deposits can occur in or outside the intrusion (example F). The relationship between crystallisation and magma mixing along sulphide solubility curves is also depicted for deposit types B, C, and D (for further details see Naldrett 1993). Examples of Australian deposits are shown in normal type and the overseas deposits are shown in italics. The latter deposits include the Merensky Reef, UG-2 (Upper Group-2 Chromitite), and LG-6 (Lower Group-6 Chromitite) of the Bushveld Complex, Republic of South Africa; the J-M Reef of the Stillwater Complex, Montana, USA; the MSZ (Main Sulphide Zone) of the Great Dyke, Zimbabwe; and the Lac des Iles Complex, Ontario, Canada.